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INTEGRATED INKJET PRINT HEAD WITH RAPID INK REFILL MECHANISM AND OFF-SHOOTER HEATER

FIELD OF THE INVENTION

001 The present invention generally relates to an integrated micro-droplet generator and more particularly, relates to a thermal bubble type inkjet head that is equipped with a rapid ink refill mechanism and off-shooter heater and a method for fabricating the head.

BACKGROUND OF THE INVENTION

002 Since the advent of printers, and specifically for low cost printers for personal computers, a variety of inkjet printing mechanisms have been developed and utilized in the industry. These inkjet printing mechanisms include the piezoelectric type, the electrostatic type and the thermal bubble type, etc. After the first thermal inkjet printer becomes commercially available in the early 1980's, there has been a great progress in the development of inkjet printing technology.

003 In an inkjet printer, a liquid droplet injector is one of the key mechanisms. To provide a high-quality and reliable inkjet

printer, the availability of a liquid droplet injector capable of supplying high-quality droplets at high-frequency and high-spacial resolution is critical.

004 Presently, there are two types of inkjet printers that are available in the marketplace, the piezoelectric type and the thermal type. The thermal inkjet system, also known as thermal bubble inkjet system, as thermally driven bubble system or as bubble jet system utilizes bubble to eject ink droplets out of an ink supply chamber, while piezoelectric printers utilize piezoelectric actuators to pump ink out from a reservoir chamber. The principle of operation for a thermal bubble inkjet system is that an electrical current is first conducted to the heater by an electrode to boil liquid in an ink reservoir chamber. When the liquid is in a boiling state, bubble forms in the liquid and expands and thus functions as a pump to eject a fixed quantity of liquid from the reservoir chamber through an orifice and then forms into droplets. When the electrical current is turned-off, the bubble generated collapses and liquid refills the chamber by capillary force.

005 When evaluating the performance of a thermal bubble inkjet system, factors such as droplet ejection frequency, cross-talk between adjacent chambers and the generation of satellite droplets are considered. Two of these performance factors, i.e. the satellite droplets, which degrade the sharpness of the image produced and the cross-talk between adjacent chambers and flow channels which decreases the quality and reliability of the inkjet system are frequently encountered. In order to improve the performance of a thermal bubble inkjet system, these drawbacks must be corrected.

006 It is therefore an object of the present invention to a provide a micro droplet generator, particularly related to a thermal bubble inkjet head that does not have the drawbacks or the shortcomings of the conventional thermal bubble inkjet head.

007 It is another object of the present invention to provide a thermal bubble inkjet head that is equipped with symmetrical heaters of the off-shooter type for generating bubbles.

008 It is a further object of the present invention to provide a method for fabricating a thermal bubble inkjet head that utilizes rapid ink refill mechanism to generate ink droplets.

009 It is another further object of the present invention to provide a thermal bubble inkjet head that is equipped with a primary and an auxiliary ink chamber.

0010 It is still another object of the present invention to provide a thermal bubble inkjet head that is equipped with two separate heaters as two sources for generating bubbles.

0011 It is yet another object of the present invention to provide a method for fabricating a thermal bubble inkjet head that is equipped with symmetrical heaters and a rapid ink refill mechanism.

0012 It is still another further object of the present invention to provide a method for fabricating a thermal bubble inkjet head that is equipped with symmetrical heaters and a rapid ink refill mechanism by utilizing two separate thick photoresist deposition processes and a nickel electroplating process.

SUMMARY OF THE INVENTION

0013 In accordance with the present invention, a thermal bubble inkjet head that is equipped with symmetrical heaters and a rapid ink refill mechanism and a method for fabricating such head are disclosed.

0014 In a preferred embodiment, a method for fabricating a thermal bubble inkjet head that is equipped with off-shooter heaters and a rapid ink refill mechanism is provided which includes the operating steps of providing a silicon substrate that has a top surface and a bottom surface; forming a first and a second insulating material layer of at least 1000Å thick on the top and bottom surfaces; reactive ion etching an opening for a manifold in the two insulating material layers on the bottom surface; wet etching a funnel-shaped manifold in the silicon substrate; forming two spaced-apart heaters on the two insulating material layers on the top surface; depositing and patterning two interconnects with a conductive metal each in electrical communication with one of the two spaced-apart heaters; depositing a third insulating material layer which may consist of two materials on top of the two spaced-apart heaters and the first insulating material layer; spin-coating a first photoresist layer of at least 2 μm thick on top of the

third insulating material layer; patterning by UV exposure a primary and an auxiliary ink chamber in fluid communication with each other in the first photoresist layer; depositing a metal seed layer on the first photoresist layer and patterning an inkjet orifice in the metal seed layer; spin-coating a second photoresist layer of at least 1 μm thick on the metal seed layer and patterning the inkjet orifice; removing the developed second photoresist layer except on top of the inkjet orifice; electroplating nickel on top of the metal seed layer encapsulating the second photoresist layer on top of the inkjet orifice; stripping away the second photoresist layer on top of the inkjet orifice; reactive ion etching from the backside away the first two insulating material layers on the top surface of the silicon substrate and the third insulating material layer exposed in the manifold; and stripping away the first photoresist layer from the primary and auxiliary ink chambers.

0015 The method for fabricating a thermal bubble inkjet head may further include the step of forming the first and second insulating material layers by either SiO_2 or Si_3N_4, or the step of wet etching a funnel-shaped manifold in the silicon substrate by KOH, TMAH, or the step of forming the two spaced-apart heaters with TaAl, or the step of depositing the third insulating material layer

with Si_3N_4 or SiC. The method may further include the step of spin-coating a first photoresist layer preferably of at least 2 μm thick, or the step of depositing the metal seed layer of Cr and Ni, or the step of stripping away the second photoresist layer by a wet etching method, or the step of stripping away the first photoresist layer from the primary and auxiliary ink chambers by a wet etching technique, or the step of patterning the inkjet orifice in the metal seed layer adjacent to a pair of the two spaced-apart heaters.

0016 The present invention is further directed to a thermal bubble inkjet head this is equipped with symmetrical heaters and rapid ink refill mechanism which includes a silicon substrate that has a top surface and a bottom surface; a first and a second insulating material layer of at least 1000Å thick on the top and bottom surfaces; a funnel-shaped manifold formed in the second insulating material layer and the silicon substrate; two spaced-apart heaters formed on the first insulating material layer on the top surface; two interconnects formed of a conductive metal each in electrical communication with one of the two spaced-apart heaters; a third insulating material layer on top of the two spaced-apart heaters and the first insulating material layer; a first

photoresist layer of at least 2 μm thick on top of the third insulating material layer; a primary and an auxiliary ink chamber formed in the first photoresist layer in fluid communication with each other and with the funnel-shaped manifold; a metal seed layer on top of the first photoresist layer and an inkjet orifice formed in the metal seed layer; and a Ni layer on top of the metal seed layer with an aperture formed therein in fluid communication with the inkjet orifice.

0017 In the thermal bubble inkjet head that is equipped with a ring-shaped symmetrical heater and a rapid ink refill mechanism, the first photoresist layer preferably has a thickness of at least 5000Å, the inkjet orifice is formed in close proximity to the ring-shaped heater; the first and second insulating material layers may be a SiO_2 layer or a Si_3N_4 layer. The two spaced-apart heaters may be formed of TaAl, the metal seed layer may be deposited of Cr or Ni. One of the two spaced-apart heaters may be positioned in the auxiliary ink chamber. The ring-shaped symmetrical heater may be positioned in the primary ink chamber. The inkjet orifice may be formed in the primary ink chamber opposite to the ring-shaped symmetrical heater. The inkjet head may be a monolithic head.

BRIEF DESCRIPTION OF THE DRAWINGS

0018 These and other objects, features and advantages of the present invention will become apparent from the following detailed description and the appended drawings in which:

0019 Figure 1A is an enlarged, cross-sectional view of a present invention silicon substrate coated with an insulating material layer on a top surface and a bottom surface.

0020 Figure 1B is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1A with an opening dry etched in the bottom insulating layer and a funnel-shaped manifold wet etched in the silicon substrate.

0021 Figure 1C is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1B with a metal layer deposited on top and formed into two spaced-apart heaters.

0022 Figure 1D is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1C with two interconnections formed each connecting to one of the two spaced-apart heaters.

0023 Figure 1E is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1D with a passivation layer deposited on top of the substrate.

0024 Figure 1F is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1E with a thick photoresist layer deposited on top.

0025 Figure 1G is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1F with a pattern formed in the photoresist layer by UV exposure.

0026 Figure 1H is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1G with a metal seed layer deposited and patterned on top for the inkjet orifice.

0027 Figure 1I is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1H with a second thick photoresist layer spin-coated on top and patterned.

0028 Figure 1J is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1I with the second photoresist layer developed.

0029 Figure 1K is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1J with an orifice plate electroplated on top.

0030 Figure 1L is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1K with the remaining second photoresist layer stripped to form the orifice.

0031 Figure 1M is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1L with the bottom insulating layer, the top insulating layer and the passivation layer stripped by dry etching.

0032 Figure 1N is an enlarged, cross-sectional view of the present invention silicon substrate of Figure 1M with the first photoresist layer stripped to form the primary and the auxiliary ink chambers.

0033 Figure 2 is a enlarged, cross-sectional view of a second embodiment of the present invention thermal bubble inkjet head equipped with two inkjet orifices for two symmetrical off-shooter heaters.

0034 Figure 3A is an enlarged, cross-sectional view of the present invention inkjet head illustrating its first operating step wherein a ring-shaped bubble is generated by the ring-shaped heater.

0035 Figure 3B is an enlarged, cross-sectional view of the present invention inkjet head illustrating the second operating step wherein the ring-shaped bubble is enlarged to push out an ink column.

0036 Figure 3C is an enlarged, cross-sectional view of the present invention inkjet head illustrating the third operating step wherein the ring-shaped bubble generated emerges into a circular bubble.

0037 Figure 3D is an enlarged, cross-sectional view of the present invention inkjet head illustrating the fourth operating step in which the bubble generated collapses.

0038 Figure 3E is an enlarged, cross-sectional view of the present invention inkjet head illustrating the fifth operating step in which a bubble is generated by the auxiliary heater.

0039 Figure 3F is an enlarged, cross-sectional view of the present invention inkjet head illustrating the sixth operating step in which a ring-shaped bubble is generated by the ring-shaped heater to restart the liquid droplet formation process.

DETAILED DESCRIPTION OF THE PREFERRED AND ALTERNATE EMBODIMENTS

0040 The present invention discloses a thermal bubble inkjet head that is equipped with a symmetrical ring-shaped heater and a rapid ink refill mechanism. The present invention further discloses a method for fabricating the thermal bubble inkjet head.

0041 In the present invention method, two separate thick photoresist deposition processes by spin-coating and a nickel electroplating process are incorporated for achieving the final structure. The first thick photoresist spin-coating process is used for forming the ink chambers which include a primary chamber and an auxiliary chamber. The second thick photoresist spin-coating process is used to form a mold layer for forming an inkjet orifice. The nickel electroplating process is used to form a top plate on the inkjet head through which an injector orifice is formed. None of these novel processing steps is used in conventional inkjet head formation methods.

0042 The present invention thermal bubble inkjet head has a construction of the monolithic type formed on a silicon single crystal substrate. A first ring-shaped heater electrode is formed in a symmetrical manner for superior liquid droplet generation. The first ring-shaped heater electrode is further formed with a high directional perpendicularity. With the present invention symmetrically constructed ring-shaped heater electrode, the problems of satellite droplets and interferences between adjacent orifices and flow channels can be minimized. Furthermore, after an ink droplet is produced by the bubbles generated by the first

heater electrode in the primary ink chamber, the second heater electrode that is positioned upstream from the primary ink chamber is activated to generate a bubble such that a flow of ink is accelerated toward the primary ink chamber. This allows a rapid ink refill mechanism for the primary ink chamber and reduces the refill time otherwise required without the second heater electrode. Moreover, the rapid ink refill mechanism increases the generating frequency for the ink droplets, which in-turn increases the printing speed of the printer that utilizes the thermal bubble inkjet head of the present invention. The various benefits and advantages described above are achieved by the present invention symmetrical ring-shaped heater electrode which can be arranged either in a off-shooter arrangement or in a back-shooter arrangement. The term "off shooter" means the position of the heater off shifted the position of the nozzle from the normal direction. An off-shooter arrangement process flow is described below, while the process flow for a back-shooter arrangement can be similarly executed with minor modifications.

0043 Referring initially to Figure 1A, wherein a silicon substrate 10 used for constructing the present invention inkjet head is shown. On a top surface 12 of the silicon substrate, and

on a bottom surface 14 of the same, is then deposited by a low pressure chemical vapor deposition method insulating material layers 16 and 18, respectively. The insulating material layers 16,18 can be formed of either SiO_2 or Si_3N_4 to a thickness of about 1000 Å, and preferably to about 2000 Å. In the preferred embodiment, a P-type 100 mm diameter silicon wafer that has a crystal orientation of (100) is utilized. A RCA cleaning procedure is first used to clean the wafer prior to processing. The SiO_2 layer may also be formed by a wet oxidation method in a furnace tube to a thickness larger than 1 μm.

0044 A first mask is then used, as shown in Figure 1B, in a photolithographic process to define the position of manifold 20 and forming the manifold 20 by first dry etching the SiO_2 layer 18 by a reactive ion etching technique, and then etching the silicon layer 22 by a wet etching process utilizing a KOH or TMAH solution. The process is completed by rinsing the wafer with DI (deionized) water.

0045 In the next step of the process, shown in Figure 1C, a second mask is first used in a photolithographic process to define the locations of the various heater electrodes 24 and 28. A

metal/alloy layer such as TaAl alloy is then evaporated on top of the insulating material layer 16 and patterned into two heater electrodes 24 and 28. The process is again completed with a DI water rinsing of the silicon wafer.

0046 Various interconnection layers 30 and 34 are then formed on top of each of the heater electrodes 24 and 28, respectively, by first depositing a metal layer and then photolithographically patterning the metal layer. A third photomask is used for the interconnection forming process shown in Figure 1D. Following the interconnection forming process, shown in Figure 1E, an insulating material layer, or a passivation layer 36, is deposited on top of the silicon substrate 10 to provide insulation to the various structures of the interconnection 30 and 34 and the heater electrodes 24 and 28. The passivation layer 36 is a protection layer which can be deposited of a material selected from Si_3N_4, SiC and SiO_2 by a plasma enhanced chemical vapor deposition technique. This is shown in Figure 1E.

0047 The present invention novel method continues by the advantageous deposition step, shown in Figure 1F, of a first thick photoresist layer 38 on top of the silicon substrate 10. The

photoresist layer 38 should have a thickness of at least 20 μm, and preferably 25-35 μm deposited by a spin-coating technique and then baked for drying. An exposure process utilizing UV radiation, shown in Figure 1G, follows by using a fourth photomask to define the size and location of the various ink chambers, i.e. the primary ink chamber 40 and the auxiliary chamber 42. A developing step is not executed at this stage such that all the photoresist layers 38, either the exposed portion 44 or the unexposed portion 48, stay on top of the silicon substrate 10. This is a critical step of the present invention and must be patterned with great accuracy such that the positions of the primary ink chamber 40 and the auxiliary ink chamber 42 can be determined.

0048 In the next step of the process, shown in Figure 1H, a metal seed layer 46 is deposited on top of the photoresist layer 38,44 and patterned to define an injection orifice 48 in the metal seed layer. The metal seed layer may be deposited of a Cr/Ni alloy by sputtering or evaporation and used as a seed layer for a subsequent electroplating process. A fifth photomask is used in a photolithography process to define the size and location of the injection orifice 48. The injection orifice 48 is formed by a wet

etching technique followed by a process for removing the photoresist layer used in the lithography process.

0049 The present invention novel method is followed, as shown in Figure 1I, by a second thick photoresist layer 50 deposition process. The deposition can be carried out by a spin-coating technique and the photoresist layer 50 is patterned for the injection passage 52. The process is then followed by a photoresist developing process, during which the photoresist layer 50 is removed except at the injection passage 52, which stays on top of the injection orifice 48. This is shown in Figure 1J.

0050 An orifice plate 54 is then formed by a nickel electroplating process, as shown in Figure 1K. The residual, second thick photoresist layer 50 in the injection passage 52 is then removed to form the injection passage in fluid communication with the primary ink chamber 40, as shown in Figure 1L. The photoresist removal process is performed by a wet etching technique.

0051 The backside of the silicon substrate 10 is then etched by a reactive ion etching technique to remove the bottom insulating material layer 18, as shown in Figure 1M, and the top insulating material layer 16 exposed in the manifold 20.

0052 In the final step of the process, as shown in Figure 1N, the first thick photoresist layer 38 is removed by a developing solution to vacate the primary ink chamber 40 and the auxiliary ink chamber 42 in fluid communication with the manifold 20 and the injection passage 52. The present invention novel thermal bubble inkjet head that is equipped with a symmetrical ring-shaped heater and a rapid ink refill mechanism is thus completed.

0053 In a second preferred embodiment of the present invention, as shown in Figure 2, a thermal bubble inkjet head 60 is provided which includes, in addition to the first injection passage 52 and the first injection orifice 48, a second injection passage 56 which is formed in a symmetrical manner to the first injection passage 52. Instead of the first preferred embodiment, the second preferred embodiment is provided with two primary ink chambers 40 and 58. The processing steps for forming the present invention

second embodiment is similar to that shown for forming the first embodiment except that a second ring-shaped heater electrode 62 and a second injection passage 56 are formed.

0054 The operation of the present invention thermal bubble inkjet head having an off-shooter arrangement is shown in Figures 3A~3F. At the beginning of the process, the funnel-shaped manifold 20, the primary ink chamber 40 and the auxiliary ink chamber 42 are filled with ink. The ring-shaped heater electrode 28 is then heated to produce a ring-shaped bubble 70. As a result, a small ink column 74 is pushed out of the ink passageway 52 through the orifice 48. At this stage, the auxiliary heater electrode 24, situated in the auxiliary chamber 42, is not heated. The ring-shaped bubble 70 enlarges, as shown in Figure 3B, to further push the ink column 74 out of the inkjet passage 52, as the ring-shaped heater electrode 28 continuously heat the primary ink chamber 48.

0055 Finally, as shown in Figure 3C, the ring-shaped bubble 70 join forms a circular bubble 76 and thus, cutting off the ink droplet 74 completely from the ink contained in the primary ink chamber 40. As a result, the inkjet droplet 74 separates from the inkjet passageway 52 and projects toward the target.

0056 After the inkjet droplet 74 departs from the inkjet head 10, the bubble 76 collapses and moves downwardly forming a void 78, shown in Figure 3D. Simultaneously within a short delay, the heater electrode 24, situated in the auxiliary chamber 42, is activated, i.e. by sending an electrical current therethrough to generate heat. A bubble 80 is thus produced. As bubble 80 enlarges while continuously heated by the heater electrode 24, it expands from the auxiliary chamber 42 toward the primary ink chamber 40 and thus, pushing ink supply 82 in a refill action into and thus resupply the primary chamber 40. The off-shooter mechanism, or off-center shooter mechanism, is thus named for the present invention inkjet droplet formation process. This is shown in Figures 3A-3D.

0057 After ink 82 is re-supplied to the primary ink chamber 40, as shown in Figure 3F, the process restarts in another cycle to produce another bubble 70 from the ring-shaped heater electrode 28. A new inkjet droplet 74 is thus reproduced.

0058 The present invention novel thermal bubble inkjet head equipped with symmetrical heaters and a rapid ink refill mechanism and a method for fabricating the head have therefore been amply described in the above description and in the appended drawings of Figures 1A~3F.

0059 While the present invention has been described in an illustrative manner, it should be understood that the terminology used is intended to be in a nature of words of description rather than of limitation.

0060 Furthermore, while the present invention has been described in terms of a preferred and two alternate embodiments, it is to be appreciated that those skilled in the art will readily apply these teachings to other possible variations of the inventions.

0061 The embodiment of the invention in which an exclusive property or privilege is claimed are defined as follows.